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Experiments in space have yielded a phenomenal amount of new information regarding the physical processes which govern our environment, and in this review it is necessary to be selective in emphasizing the major scientific applications of space research to the exclusion of other developments which might be included in a fuller discussion.

These basic scientific applications of space flight vehicles are only a part of the space program, but they are extremely important because out of them come the advances in our understanding of the basic physical laws which mold our environment -- an understanding on which all the technological developments of our present-day society are based to a large degree, and on which all our future achievements will depend.

What are these major lines of scientific inquiry in the space program, and the problems which provide the basic motivation for the space science experiments? In the physical sciences these basic problems of space science include a very large area which cuts across the boundaries of astronomy, physics, and the earth sciences, but in spite of the variety of space investigations, all the scientific experiments are designed to illuminate only three central areas of science:

<u>the structures of stars and galaxies</u>: the evolution of stars;

nuclear synthesis of the elements in the universe.

<u>the origin and evolution of the solar system</u>: the formation of the sun; the early histories and present structures of the planets;

<u>the way in which the sun controls the atmosphere of the earth</u>: the causes of weather activity in the lower atmosphere; the structure of the upper atmosphere.

Among these three major lines of inquiry the contribution of the space program to the first two is largely potential, and its promise for the future rests on projects now under development but not yet completed. The third area has been greatly stimulated by the rocket and satellite projects of the IGY and the first years of the space program, and has already seen great activity. It is one of the most exciting and fruitful fields of research in the space science program, and it will therefore be discussed at length.

Although a serious space investigation of the first problems, related to the evolution of the stars, is still several years off, a start has been made on the second set of problems associated with the origin of the solar system and the development of planetary bodies.

Two major branches of science are united in the study of this problem: astro-physics, in the consideration of processes attendant on the development of the primitive sun and the formation of the surrounding solar nebula; and geophysics, in the attempt to deduce the early histories of the planets from their present structures. The efforts to join these two fields and to roll back the history of 4.5 billion years, to unravel the tangled complex of physical and chemical processes accompanying the birth of the planets, is one of the most interesting problems in modern science.

In the investigation of these questions, the physical exploration of the moon and the planets by unmanned and manned spacecraft will play a unique role in providing us with our first opportunity for a comparative study of the structures of the planets. The moon in particular should yield information of exceptional interest, because its surface is likely to have preserved a record of past events going back billions of years, unmarred by the erosive effects of atmospheres and oceans, and relatively unchanged by mountain-building processes. (See Figure 1). This is a record lost on the earth, probably lost on Mars and Venus, and probably available nowhere else in the solar system on a relatively accessible body.

A thorough exploration of the moon and the planets is some years off but preliminary explorations of the moon by unmanned vehicles are scheduled by the United States for early 1962, and the Soviet Union has already achieved results of great importance with the Lunik III spacecraft, by which the first images of the moon's hidden face were secured.

In spite of some blurring of the Lunik III photographs, they are still of great interest, for it is possible to distinguish on them a large number of features resembling the craters and maria on the front face. Perhaps the most interesting feature is the Soviet Mountain Range, a chain extending across the center of the moon's hidden face. The Soviet Range resembles the great ranges on the earth; it does not look like the formations characteristic of the mountains on the front face of the moon, which seem to be circular crater walls and deposits of debris formed by the impact of large meteorites on the lunar surface. (See Figure 2)

According to our present ideas, terrestrial mountains result from the combined effects of erosion and the wrinkling of the earth's crust produced by the slow shrinkage of our planet. The current consensus is that these mountain-building forces have been much less effective on the moon. The markings referred to as the Soviet Mountains could have resulted from the running together of several obscured but independent markings; but we may have to revise our theories of lunar structure if they continue to appear as a single range in later and more detailed pictures.

The US has just embarked on its own program for the exploration of the moon, of which the first stage is the delivery to the moon's surface of a package of instruments to be carried on board the RANGER spacecraft. (See Figures 3 and 4) The RANGER is constructed to take pictures of the moon's surface from as close a distance as ten miles, which will reveal details of the surface as small as a few yards across, that is, hundreds of times finer than the best photographs of the moon taken from the earth. These photographs will be of immense value to us in developing our program of manned lunar landings.

The RANGER also carries a seismometer, an instrument for detecting earthquakes, which will be separated from the main body of the spacecraft and slowed down to the relatively gentle speed of 300 miles per hour as it approaches the moon's surface. Although the jolt of the landing will be equivalent to the impact of a DC-7 hitting the side of a mountain. This delicate instrument is nonetheless designed to survive the impact, and to transmit data back to earth on the occurrence of "moonquakes", for a period of a month or longer, with the aid of a small radio transmitter attached to it. Such seismic measurements are the source of most of our knowledge ragarding the interior of the earth, and they are also expected to tell us what the interior of the moon is like.

The third major area of investigation in space science concerns the control exerted by the sun over the atmosphere of the earth. This is the earea in which we have made major advances during the first era of the space program. It includes questions related to weather and atmospheric circulation, and to the structure of the atmosphere at high altitudes.

Regarding weather prediction, three TIROS satellites have been launched in the past eighteen months, all carrying TV cameras for the global study of clouds, which have already been successful in some cases in revealing potential hurricanes. (See Figures 5 and 6)

We turn now to the area of research relating to the upper atmosphere and its extension into the interplanetary medium, an area in which our knowledge is increasing very rapidly. It is at present a very exciting and fruitful field of research for both the theoretical and the experimental scientist, and one largely unexplored until now, because before the age of satellites and space experiments there was no way to get fundamental data on the atmosphere and space environment. Our knowledge of atmosphere properties -- which had been limited essentially to altitudes below 60 miles at the start of the International Geophysical Year in 1957 -- has been expanded with the aid of rockets and satellites to the point where we now have a fairly good picture of the atmosphere at heights up to 1000 miles, and isolated results well above that level. We know that the atmosphere near the ground is primarily a mixture oxygen and nitrogen, with a layer of atomic oxygen above extending out to 600 miles. Until this past year it had been assumed that the oxygen and nitrogen, which are relatively heavy gases settle out at the bottom of the atmosphere, and that the atmosphere at great heights is composed primarily of hydrogen the lightest of all gases.

The boundary between the hydrogen layer and the heavier gases was believed to be at a height of about 600 miles. However, in 1961 Prof. Marcel Nicolet of Belgium predicted that helium would fill the atmosphere above 600 miles, and shortly after his prediction, instruments carried on the Explorer VIII satellite confirmed the prediction by revealing a large amount of helium in the upper atmosphere. The helium extends from 600 to 1500 miles, forming a layer 900 miles thick.

Above the boundary of the helium layer the atmosphere changes to hydrogen gas. The hydrogen atmosphere persists up to about 6000 miles, where it merges into the interplanetary gas. This height should mark the boundary of the earth's atmosphere.

However, early in 1958 Professor James Van Allen of the State University of Iowa discovered that there was an additional layer of particles in the upper atmosphere, with very high energies, extending up to millions of volts. These particles are often called the Van Allen Radiation Belts.

Particles with such high energies could easily escape from the atmosphere if it were not for the magnetic field of the earth, which traps them and forces them to move around the earth for long periods of time. These particles actually form an outermost layer of the atmosphere, extending out much further than we used to think the atmosphere could reach. They go out as far as 60,000 miles, about ten times further than the older boundary of the atmosphere. The Van Allen layer of the atmosphere is called the magnetosphere, because it could not exist without the trapping action of the earth's magnetic field. (See Figure 7)

The discovery of the magnetosphere by Van Allen is the most significant scientific event of the first years of the space program. It has generated a great volume of research, and has thown a new light on the relationship between the sun and the earth.

Interest in the Van Allen particles was initially concentrated on the radiation danger which they present to astronauts in manned space travel, but we now know that the scientific importance of this discovery is related less to the radiation problem than to the role which these particles play in controlling the upper atmosphere. The Van Allen zones seem to be involved in the process by which energy is transferred from the sun to the earth at the time of major solar eruptions. This energy involves changes in the density and temperature of the atmosphere, and there has even been some suggestion of a connection between flares and the weather.

Flares produce enormous changes in the intensity of the Van Allen belts, which are connected to the other effects accompanying solar activity, in a way we do not yet understand clearly. However, we think that these Van Allen zones, and the whole magnetosphere of which they are a part, constitute a reservoir in which solar flare energy can be stored in the form of trapped particles for a considerable time, until some subsequent solar event disturbs the magnetic field and dislodges particles from the Van Allen belts, as apples are shaken from a tree. As to the mechanism of the shaking, it is believed that when the incident solar plasma cloud impinges on the geomagnetic field, it produces irregularities in the field which scatter the particles out of their spiralling orbits around the lines of force. When the particles are dislodged from the magnetosphere they descend through the horns of the Van Allen zone, transferring their kinetic energy to the atmosphere by ionizing collisions. This is probably the cause of the aurora, or northern lights, whose origin has been a matter of mystery and speculation for centuries. Thus a satellite discovery has already supplied the answer to one of the age-old problems of science. Figure 8 shows the way in which the magnetic field of the earth channels the active auroral regions in the arctic and antarctic zones.

The latest development in space science is the discovery of the manner in which clouds of solar particles are transmitted through interplanetary space to the earth, to cause the aurora and other effects in our atmosphere. These clouds of particles are produced at the surface of the sun, which boils and bubbles actively, and occasionally erupts in a giant outburst known as a solar flare. (See Figure 9)

When a flare occurs in the right position on the part of the sun's surface pointed toward the earth, the cloud of particles ejected during the flare travels across space and collides with our atmosphere. Such clouds move at about 1000 miles per second, and take about one day to reach us travelling at that speed. Although the energy carried by the particles in the clouds is only one millionth of the energy radiated by the sun in the form of visible light, and its effects are usually not noticed by the man in the street, they can, nonetheless, be very important. It produces the aurora which we have already discussed, as well as blackouts of radio signals, magnetic storms, and violent changes in the intensity of the Van Allen belts.

In 1960 several great flares of unusual violence occurred at times when the American satellites Explorer VII and Explorer VIII and the Pioneer V spacecraft were out in space with instruments designed to study the effects of these flares. During 1961, a fascinating picture of the solar particle clouds has emerged from the close study of these space glight data combined with ground observations. We have discovered that a solar cloud drags with it lines of magnetic force, which are frozen into the cloud and forced to move with it by the laws of electromagnetism. These lines of magnetic force have their roots on the surface of the sun in the vicinity of the flare, but as the plasma tongue moves across space they are drawn out with it like loops of taffy. When the earth has been enveloped by the cloud the lines of magnetic force, which it contains, deflect charged particles from our planet, and shield us from the cosmic rays by which we are otherwise bombarded at all times. Mr. Scott Forbush of the Carnegie Institute in Washington D. C. first discovered that cosmic rays drop off after flares, some 20 years ago, but the explanation of the decrease was a mystery, until space experiments revealed that it was caused by solar clouds in the manner we have described.

The deflecting action of magnetic fields within the cloud also traps particles which are already in its interior, preventing them from escaping. Thus the solar cloud acts as a bottle which can contain charged particles for extended periods of time. Since the magnetic field in the cloud provides the bottling action, scientists call it a magnetic bottle.

The existence of magnetic bottles was discovered only last year. The data clearly show that when the earth enters the bottle formed by the solar cloud, it is fiercely bombarded by particles contained in the bottle, while at the same time there is a decrease in the normal bombardment by cosmic rays. (Figure 10) It is only by the combination of space flight and ground-based observations that we have been able to gain this understanding of the manner in which solar flares affect the earth. This is a major step forward in our understanding of sun-earth relationships and a good example of the rapid progress which space research can bring to science.